Assessment of Global Rare Earth Supply & Wind Energy Growth: Opportunities and Challenges

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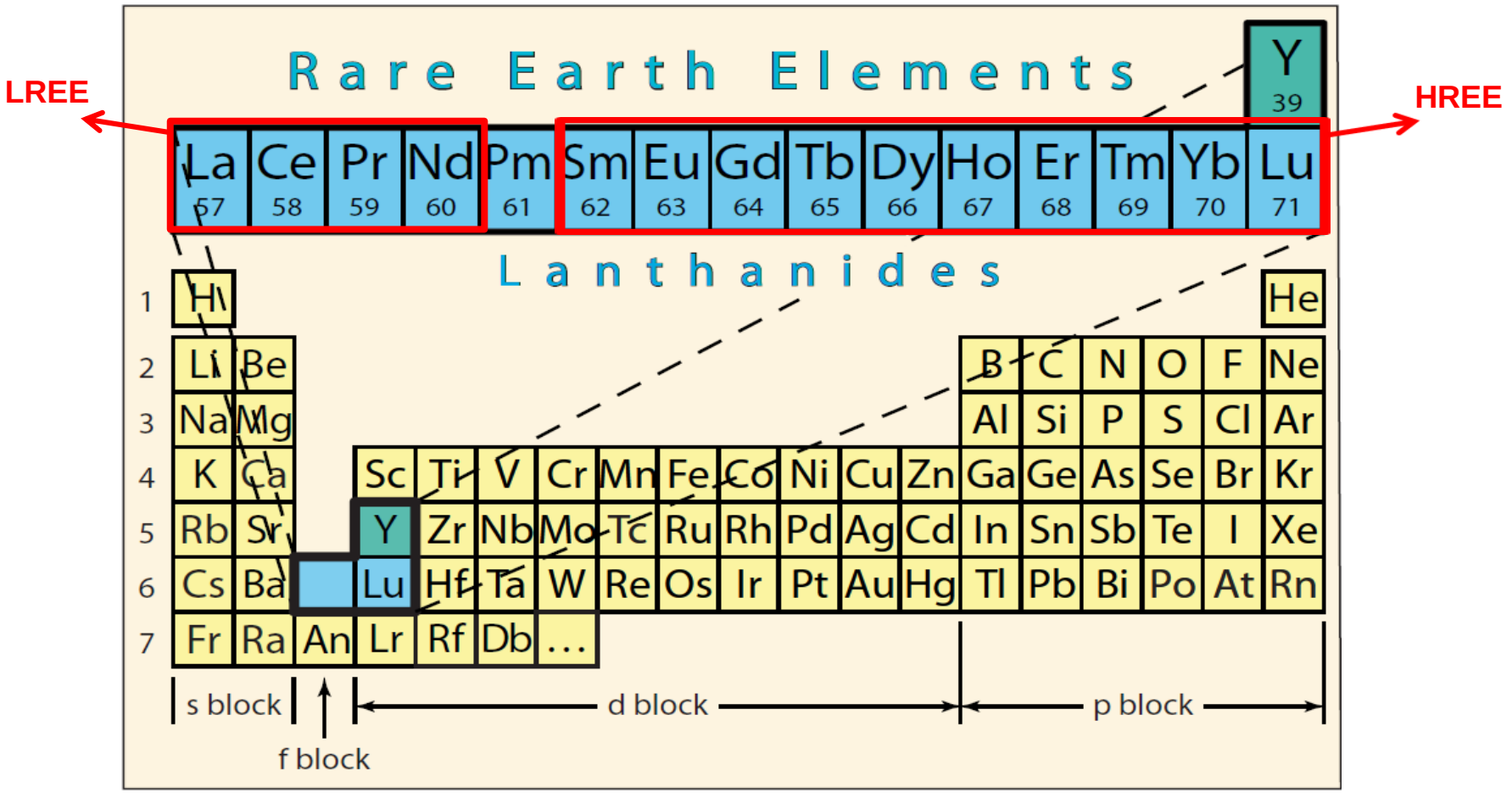
Green and Sustainable Chemistry Conference, Berlin, Germany, 4-17th May. 2017

Presentation Outline

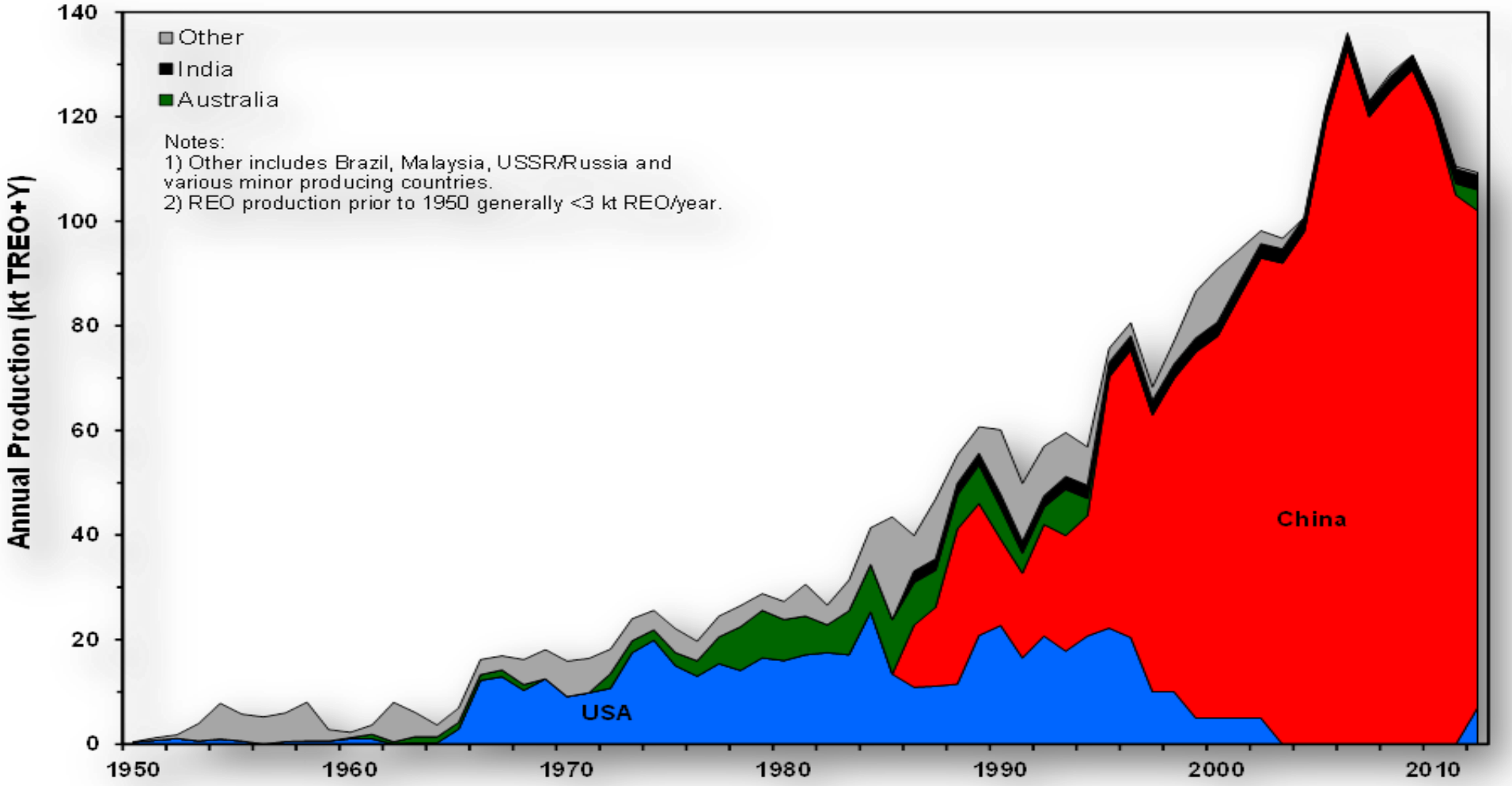
- Brief Review of Rare Earth Elements (REE)
- Global REE Supply
- Global REE Mineral Resources Assessment
- Environmental Implications of REE Production
- REE Demands from Wind Energy Development
  - The case of NdFeB permanent magnet
- Summary: Challenges & Opportunities

Rare Earth Elements (REE) Overview



Source: USGS Open-File Report 2005-1219

Global REE Supply



Source: USBoM (various-a,b), USGS (various-a,b,c;), USGS 2013; Australian REO based on monazite production data from BoMRGG (various) and under the assumption of minimum 60% contained REO.

Global REE Mineral Resources Assessment

Mineral Resources

The location, quantity, grade, geological characteristics and continuity of a mineral resource are known such that there are reasonable prospects for eventual economic extraction, although not all modifying factors have been assessed and hence some uncertainty remains. Mineral Resources are sub-divided, in order of increasing geological confidence, into *'Inferred'*, *'Indicated'*, and *'Measured'* categories.

Source: CRIRSCO,2012

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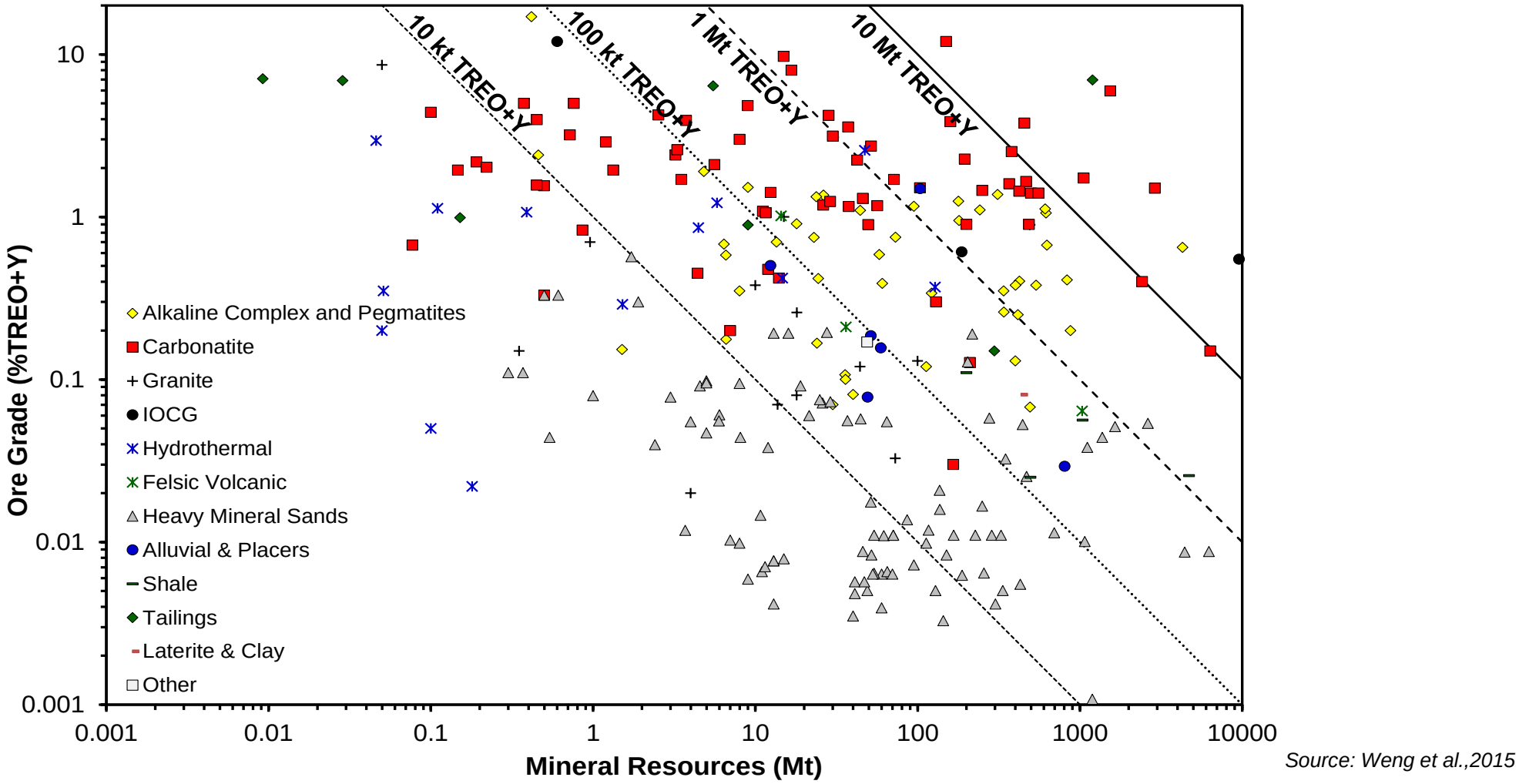
Global REE Mineral Resources Assessment

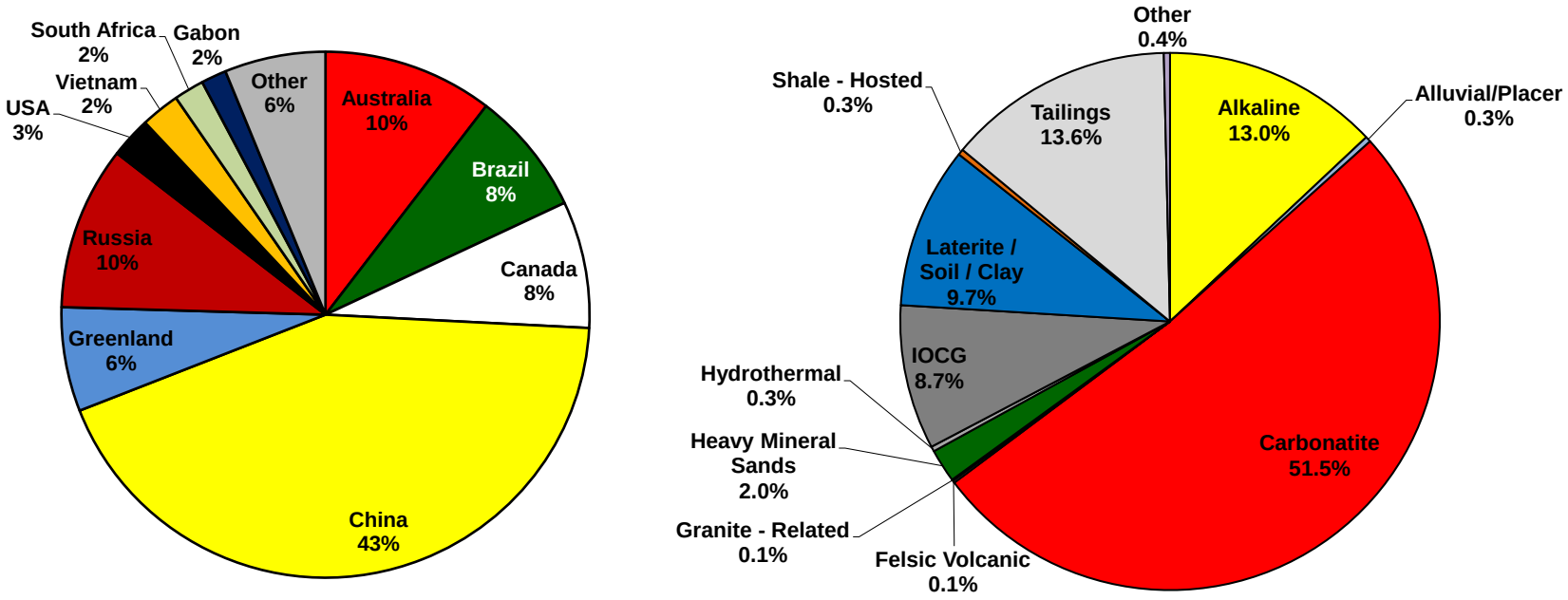
Source: Weng et al.,2015

Global REE Mineral Resources Assessment



Source: Weng et al.,2015

Global REE Mineral Resources Assessment



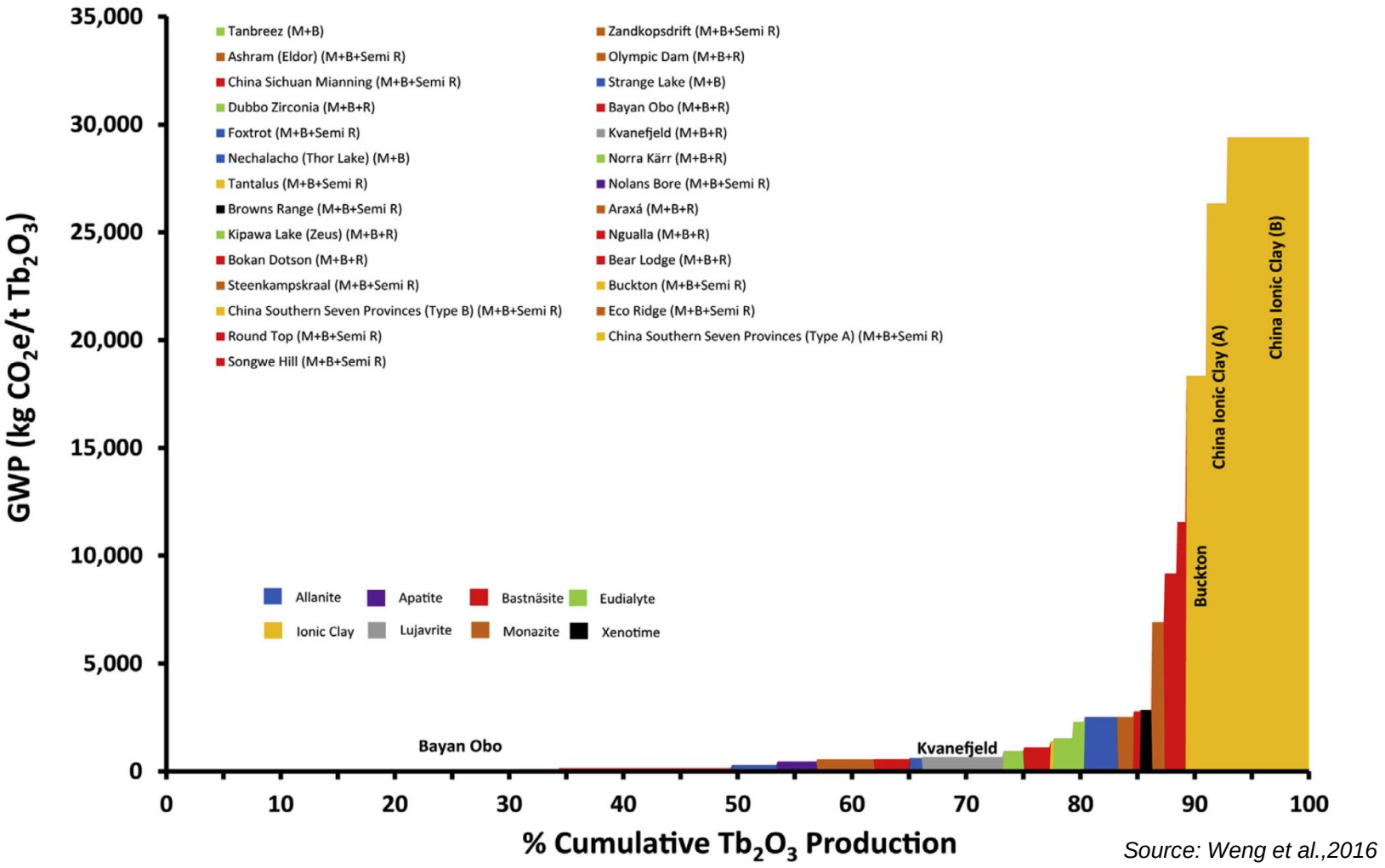
Percentage of REO resources split by country (left) and by principal deposit type (right). *Source: Weng et al.,2015*

Our assessment (based on 2013-2014) suggests a minimum global REE mineral resource of 619.5 Mt REO at an average grade of 0.63% contained within 267 deposits, with 57% of these resources are hosted by deposits outside of China. It highlights the possibility to establish a more diverse global REE supply chain.

Environmental Implications of REE Production

- ***Deposit Type – Mining Process***
- ***Mineralogy – REE Recovery Process***
- ***"Conventional" carbonatite based REE deposit has low HREE concentrations***
- ***Very limited knowledge of REE recovery from 'unconventional' REE deposits (e.g. HMS).***
- ***Hazardous / Radioactive impurities or by/co-products (Th, U) are difficult to separate.***

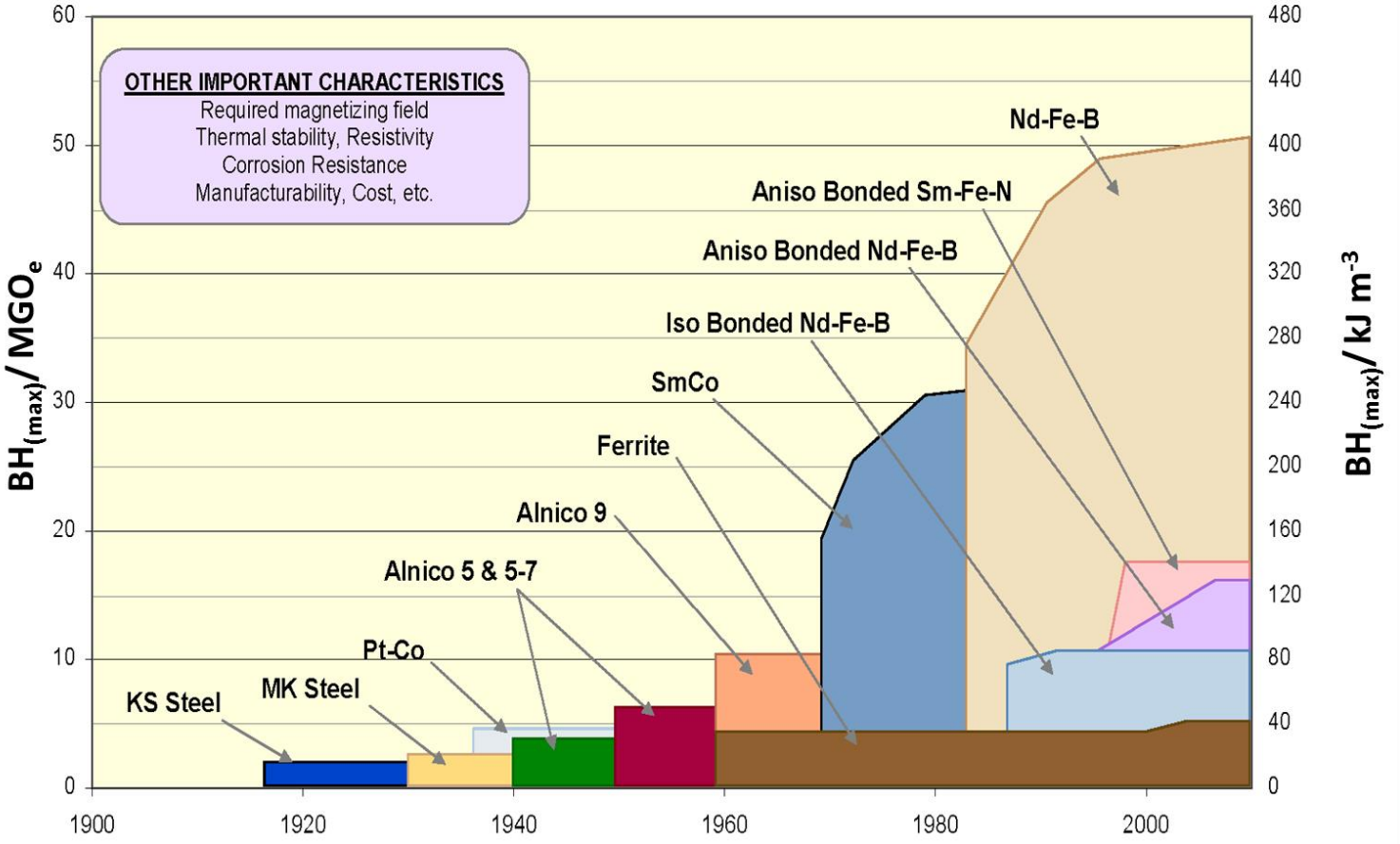
Our assessment suggests an average global warming potential (GWP) footprint of 83 t CO2-e/t REO, while the average GWPs for iron ore, bauxite and copper concentrate productions are 11.9 kg CO2-e/t, 4.9 CO2-e/t and 0.63 t CO2-e/t respectively.



Source: Weng et al.,2016

REE Demands from Wind Energy Development

REE-dependent permanent magnets provide significantly better **"maximum static energy product" capacity BH(max)** compared to traditional aluminum-nickel-cobalt (Alnico) and ceramic (Ferrite) magnets. Given their superior magnetic strength (e.g., NdFeB magnet) and excellent resistance to demagnetization at elevated temperatures (SmCo magnet) REE permanent magnets have become essential components for various permanent magnet synchronous generators (PMSG) Wind Turbines designs and manufacturers.



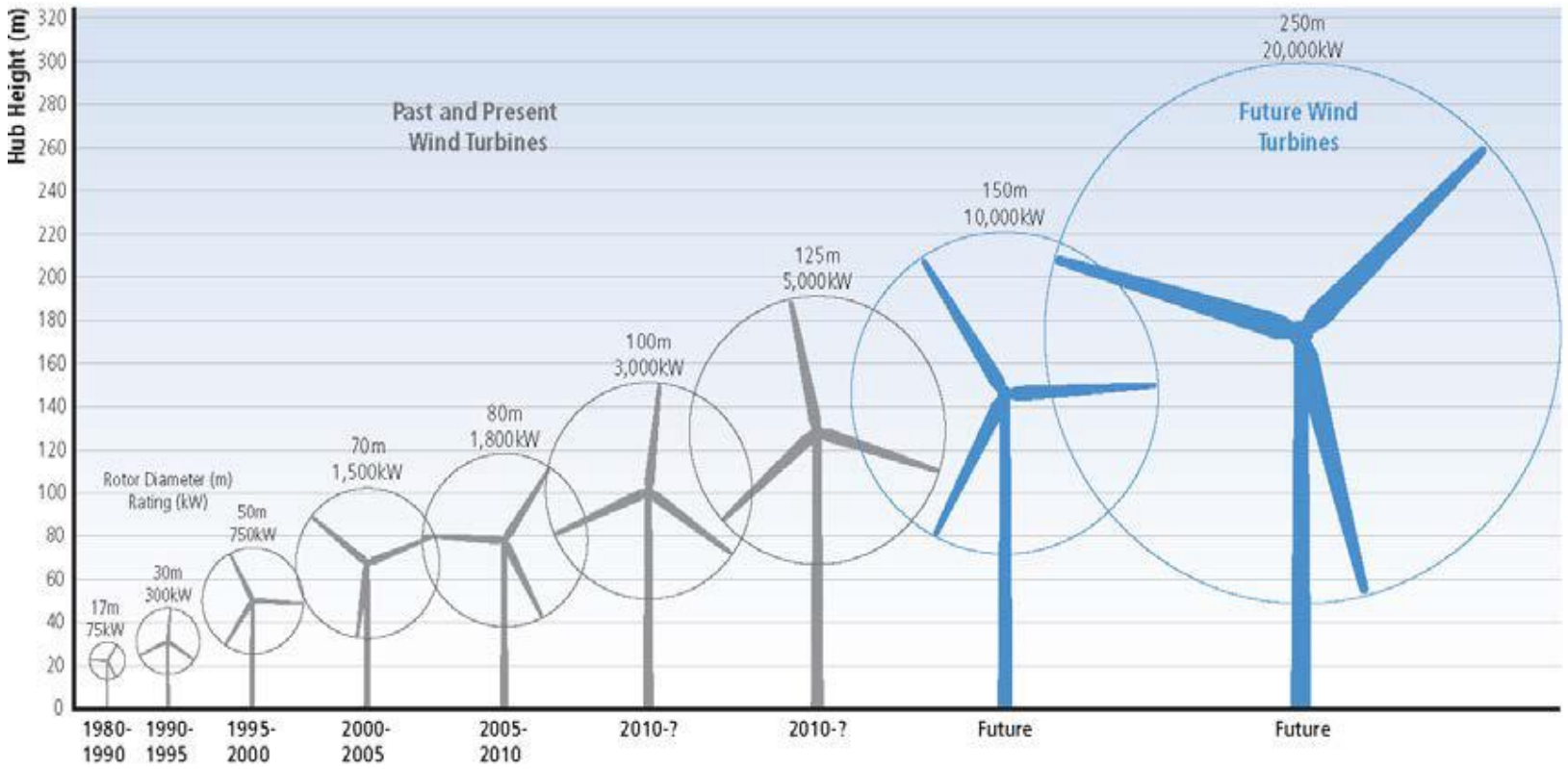
Source: Arnold Magnetic Technologies,2016

REE Demands from Wind Energy Development

The overall trend of Wind Turbine Development

- Larger wingspan
- Utilization of light weight material/design
- Longer Product Life cycle
- Adaptability of lower wind speed
- Onshore system ⟶ Offshore system Development
- More PMSG

REE permanent magnet is key component in meeting these demands!



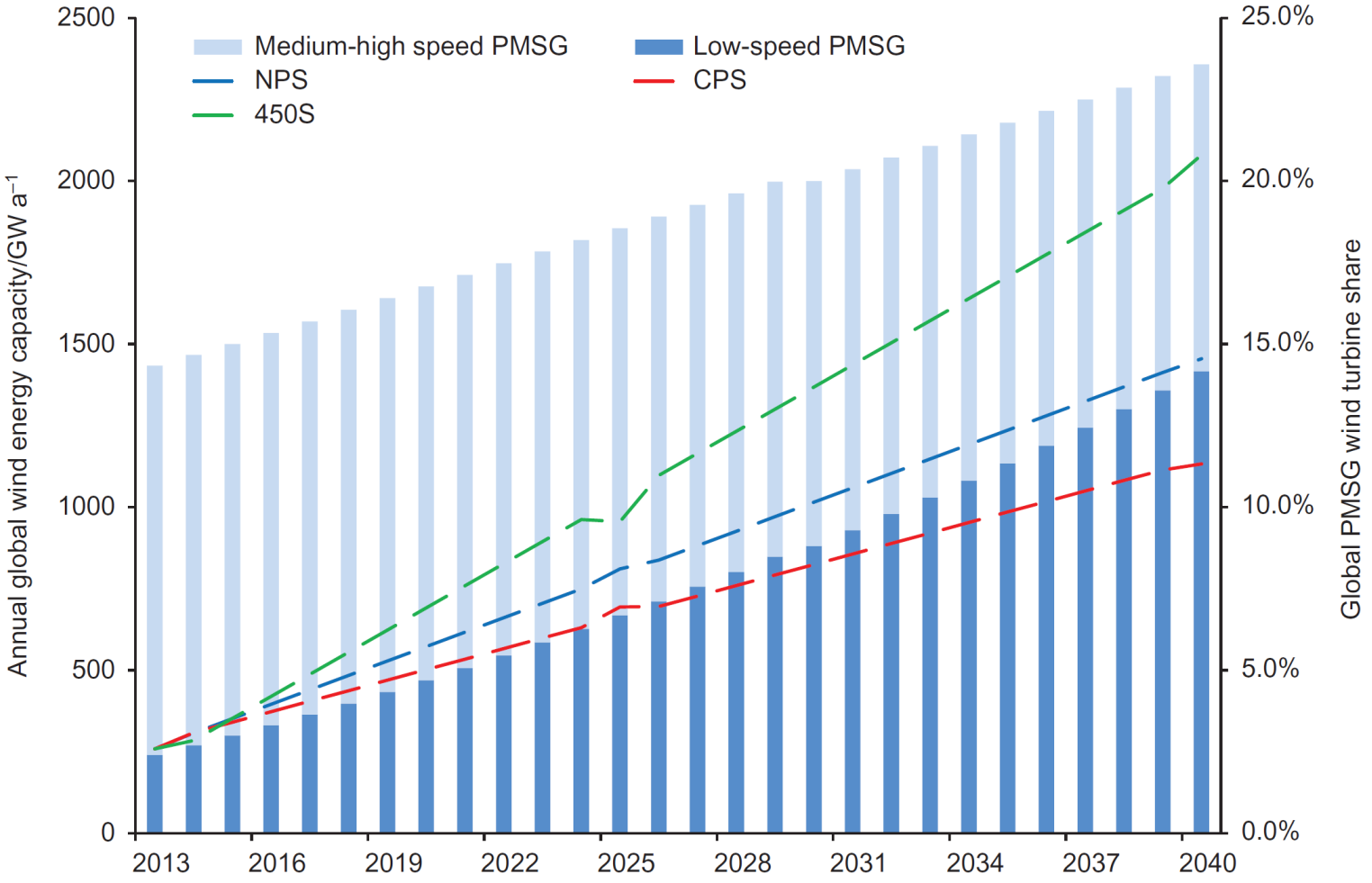
Source: Wiser et al., 2011

REE Demands from Wind Energy Development

The International Energy Agency (IEA) predicts the evolution of the global energy sector toward 2040 with three main scenarios, specifically

1. The Current Policies Scenario (CPS);
2. The New Policies Scenario (NPS);
3. The 450 Scenario (450S).

For detailed assumptions and implications for scenario, please refer to the World Energy Outlook (IEA, 2015).



Source: EWEA, 2015; GWEC, 2015; IEA, 2015; Moss et al., 2013

REE Demands from Wind Energy Development

System	REE	Value (kg MW^{-1})
Medium-high speed PMSG (Onshore wind turbine)	Nd	24
	Dy	2
	Tb	0.8
Low-speed PMSG (Offshore wind turbine)	Nd	207
	Dy	18
	Tb	7

Source: Moss et al., 2011; Öhrlund, 2011

REE Demands from Wind Energy Development

REE	Wind Energy Scenario	Cumulative Demands (kt)	Mineral Resources (kt)
Dy	CPS	35	4 601
	NPS	44	
	450S	58.7	
Nd	CPS	419	72 821
	NPS	515	
	450S	692.6	
Tb	CPS	14	973
	NPS	17	
	450S	23.5	

Source: Weng et al., 2017

Summary: Challenges & Opportunities

- The REE geological scarcity is not an immediate problem. For example, we project that the cumulative demands till 2040 of Nd (692.6 kt) accounts for less than **0.1%** of identified resources.
- However, due to inequality in REE concentration within carbonatite hosted REE mines (i.e. Bayan Obo), it requires 1.01 Mt annual REO production capacities from single deposit; while actual China's annual production is about 95,000 t REO in 2014.
- This is only based on the demands from **ONE Sector – PMSG** Wind Turbine Production. What about REE demands from other emerging technologies (e.g. Hypid / Electrical Automobiles)?
- Hence, how to sustainably and efficiently extract REE from other "unconventional" REE sources (e.g. HREE enriched deposits, REE recycling / urban mining) is another challenge for future global REE supply.

Acknowledgements

Prof. Gavin Mudd, Prof. Simon Jowitt & Dr. Nawshad Haque for their guidance and support!

Dr. Stephen Northey, Dr. Tim Werner & many other academic colleagues for sharing their insights.

Australia's CSIRO Mineral Resources Flagship for funding this project.

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Thank you for your attention !

Any questions?